Carbon Nanotubes (CNTs)

By

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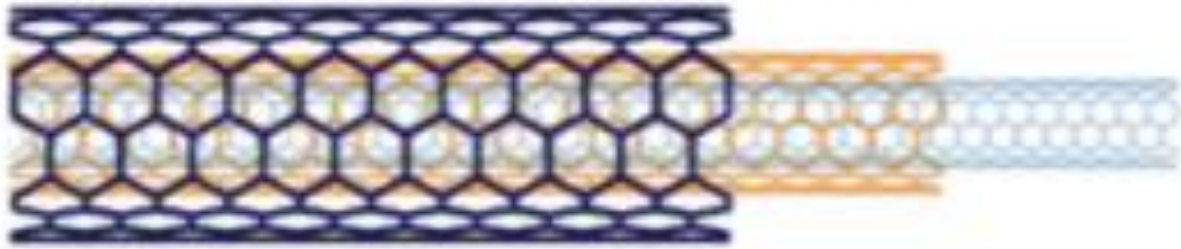
Emerging trends in



Carbon nanotubes (CNT)

- Properties
  - Mechanical
  - Surface
  - Energy related
  - Thermal
  - Physical
  - Others
- Materials
  - Composites
  - Others
- Applications
  - Sensors
  - Energy conversion
  - Electronics
  - Energy storage
  - Clean energy
  - Environmental
  - Biomedical

Carbon Nanotubes

- Carbon nanotubes (CNTs) are a one-dimensional (1-D) allotrope of carbon, made up of a sp2 hybridized carbon lattice in the form of a cylinder.
- A single-wall CNT (SWCNT), the simplest version of a CNT, consists of a single, cylindrical graphene tube.
- In double-wall CNTs (DWCNTs) and multiwall CNTs (MWCNTs), two or more tubes are either nested concentrically or wrapped like a scroll.
- SWCNTs are typically 0.4–2 nm in diameter, while MWCNTs can be much larger, with diameters of tens of nanometers, having both ends generally capped by fullerene-like domes.

Carbon Nanotubes

- Similar to fullerenes and graphene, which are the analogous 0- and 2-D allotropes of carbon, the graphite-like arrangement of carbon atoms in CNTs and their shape give them remarkable and unique properties, which has resulted in the widespread use of CNTs in several fields of science and technology, including energy storage, electronics, structural composites, biomaterials, and others.

Carbon Nanotubes

- Because of their 1-D structure, CNTs have highly anisotropic mechanical, electrical, and thermal properties, which make them ideal for use in polymer, ceramic, and metal matrix composites.
- Additionally, their electrical properties, very high surface to volume ratio, and potential for chemical functionalization has led to their use in battery and supercapacitor components.

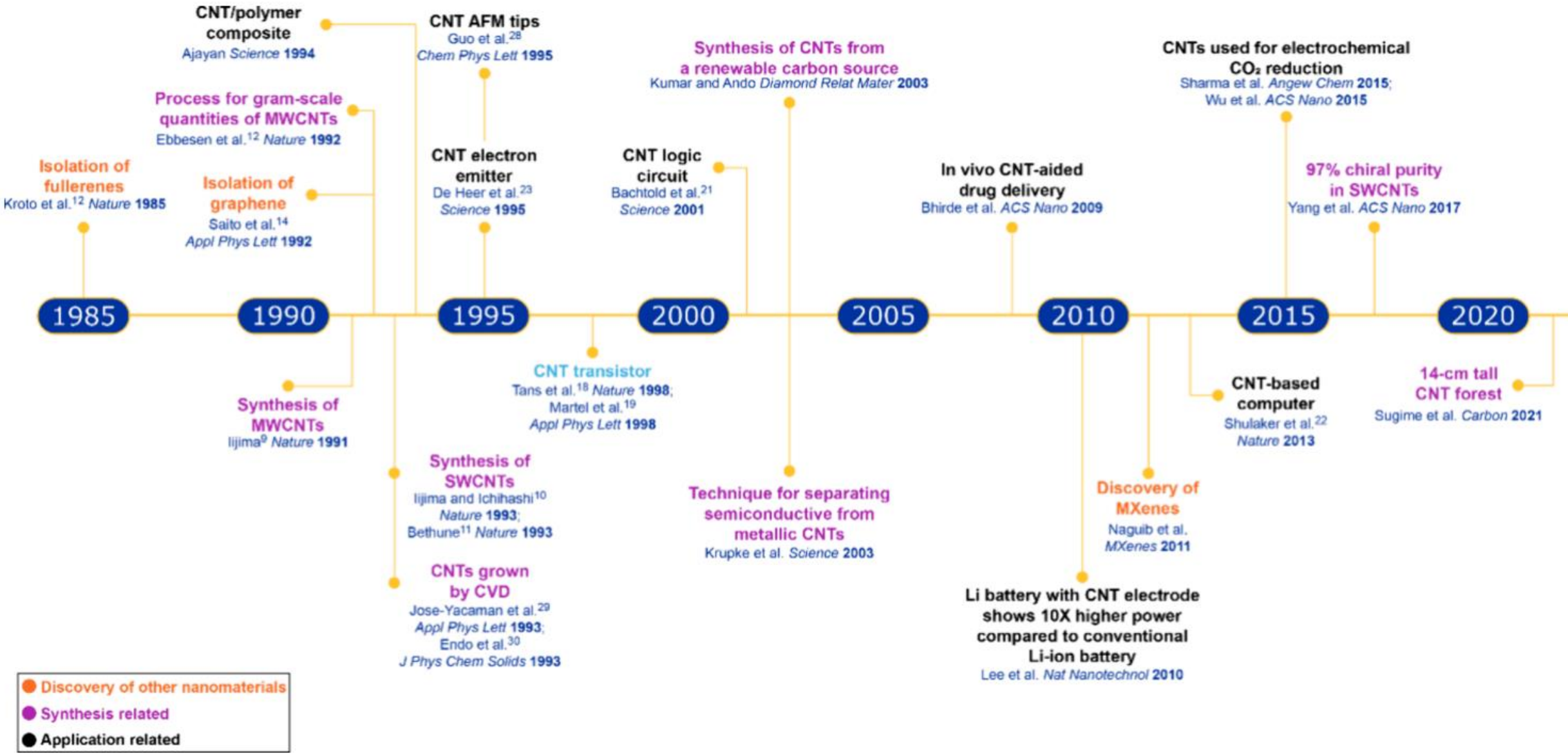


Figure 1. Timeline showing notable events in the recent history of CNTs and other notable nanoscale materials. Events have been color coded to indicate area of work (synthesis (purple), application (black) or discovery (orange)).

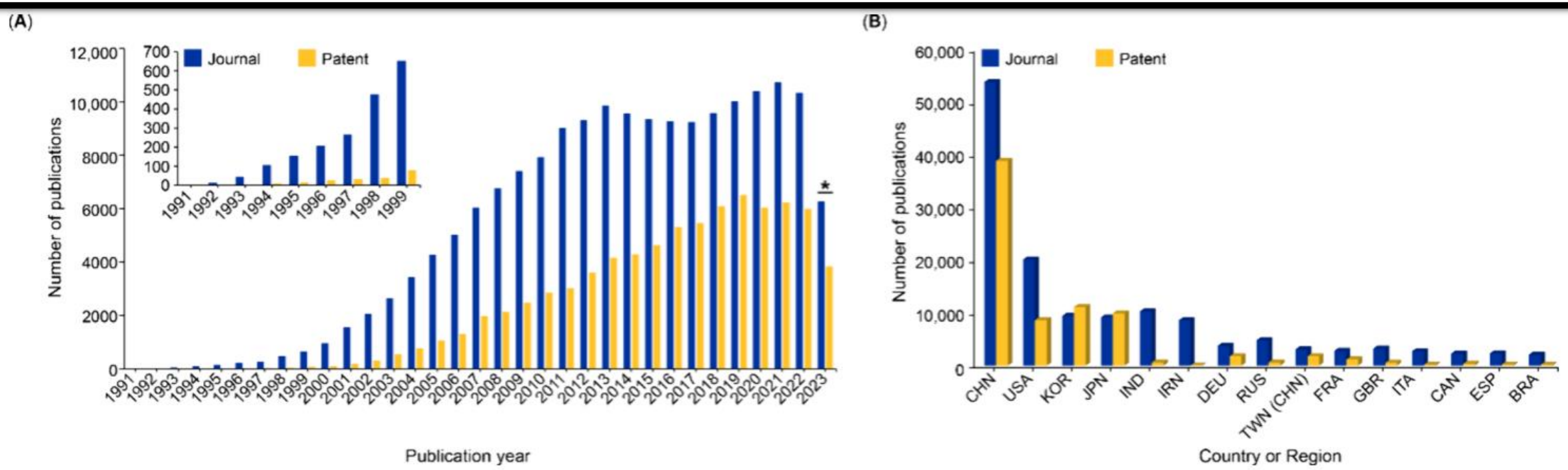


Figure 2. (A) Overall publication trend for CNT-related research between 1991 and 2023. (B) Leading countries or regions in CNT-related research between 2003 and 2023. Data includes journal and patent publications from the CAS Content Collection. **The data for 2023 is partial and only includes data from January to July.*

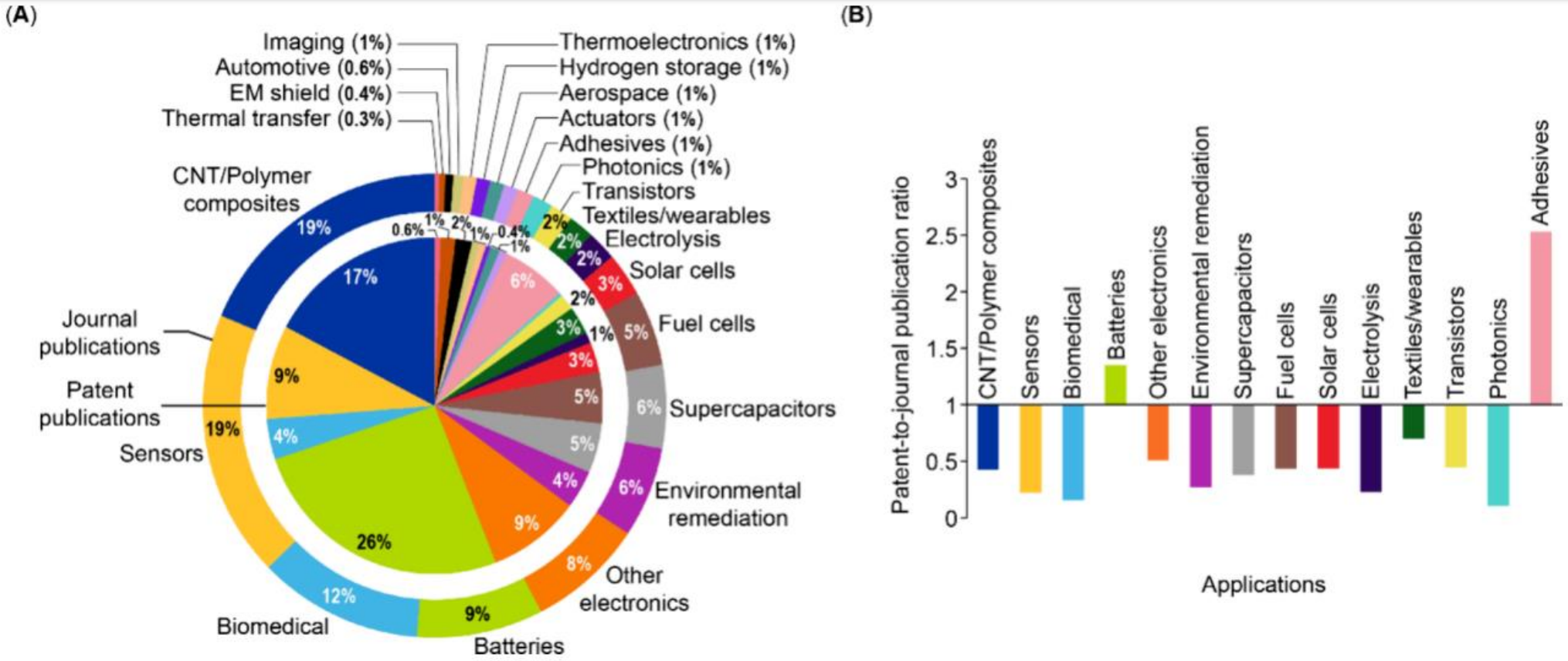


Figure 5. (A) Pie chart showing the distribution of publications related to individual CNT applications for journals (outer) and patents (inner). (B) Ratio of patent to journal publications for selected applications. Data includes journal and patent publications in the field of carbon nanotubes from the CAS Content Collection for the period 2003−2023.

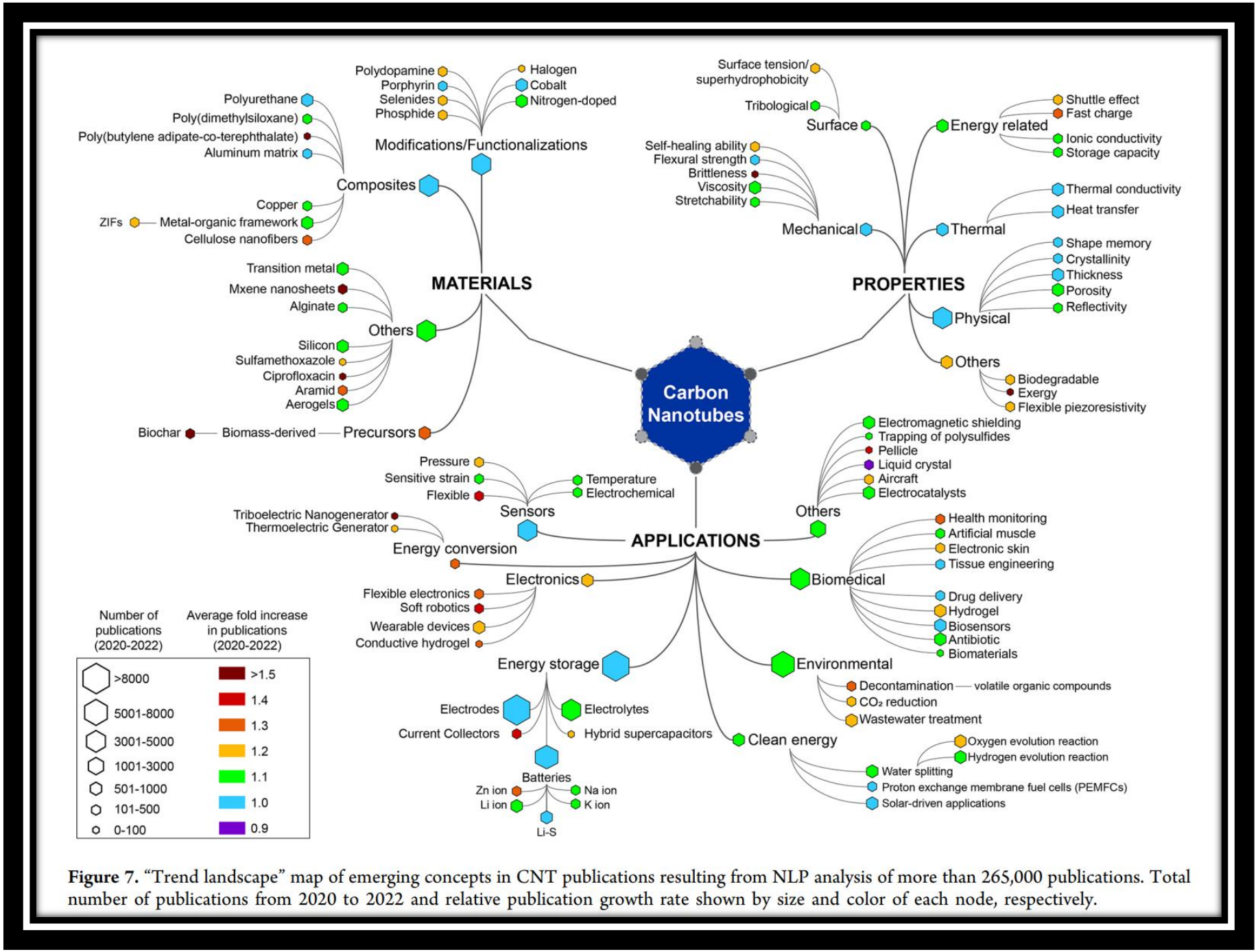


Figure 7. "Trend landscape" map of emerging concepts in CNT publications resulting from NLP analysis of more than 265,000 publications. Total number of publications from 2020 to 2022 and relative publication growth rate shown by size and color of each node, respectively.

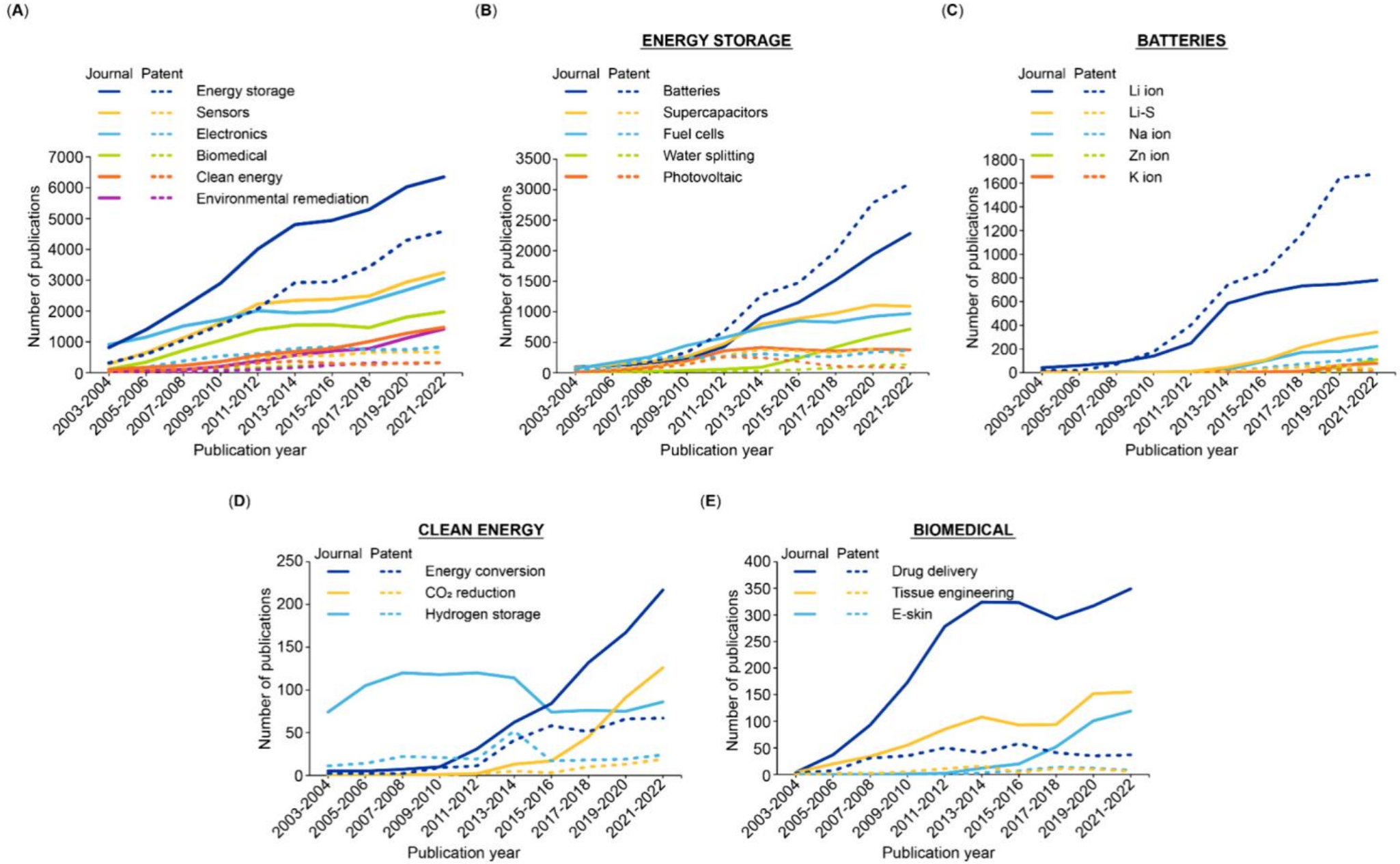


Figure 8. Time trends for selected concepts and concept groups from Figure 7. Growth in journal and patent publications for (A) broader emerging applications, and applications specific to (B) energy storage, (C) batteries, (D) clean energy and (E) biomedical. Data includes patent and journal publications in the field of CNT-related research from the CAS Content Collection for the period 2003–2022.

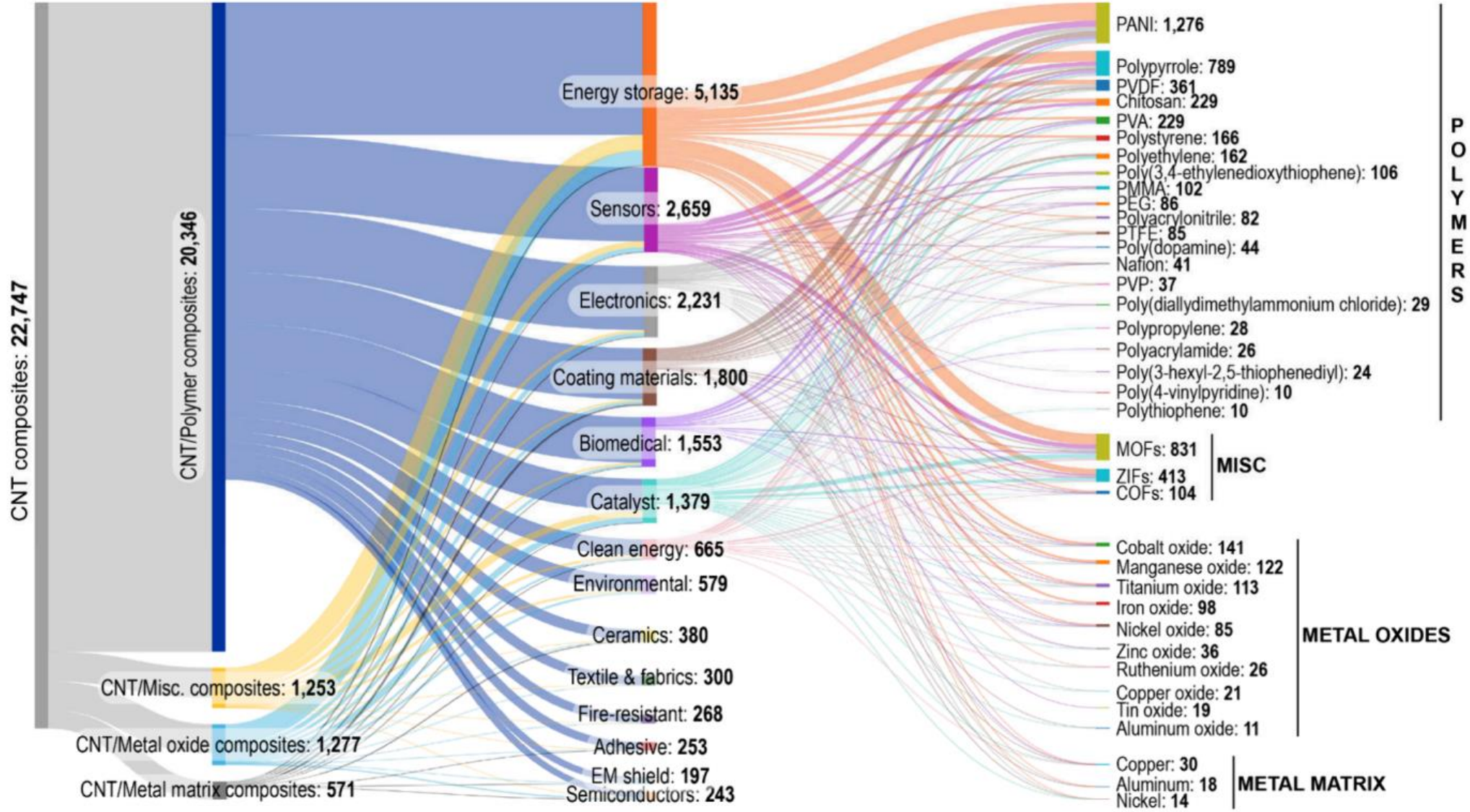


Figure 9. Breakdown of CNT composites based on journal publications in the field of CNTs from the CAS Content Collection for the period 2003–2023. The second and third columns show types of CNT composites and applications in which they are frequently utilized, respectively. The column on the extreme right shows individual polymer, metal oxide and metal matrix materials as well as materials such as metal–organic frameworks (MOFs), zeolite imidazole frameworks (ZIFs) and covalent organic frameworks (COFs) grouped under CNT/Misc. composites.

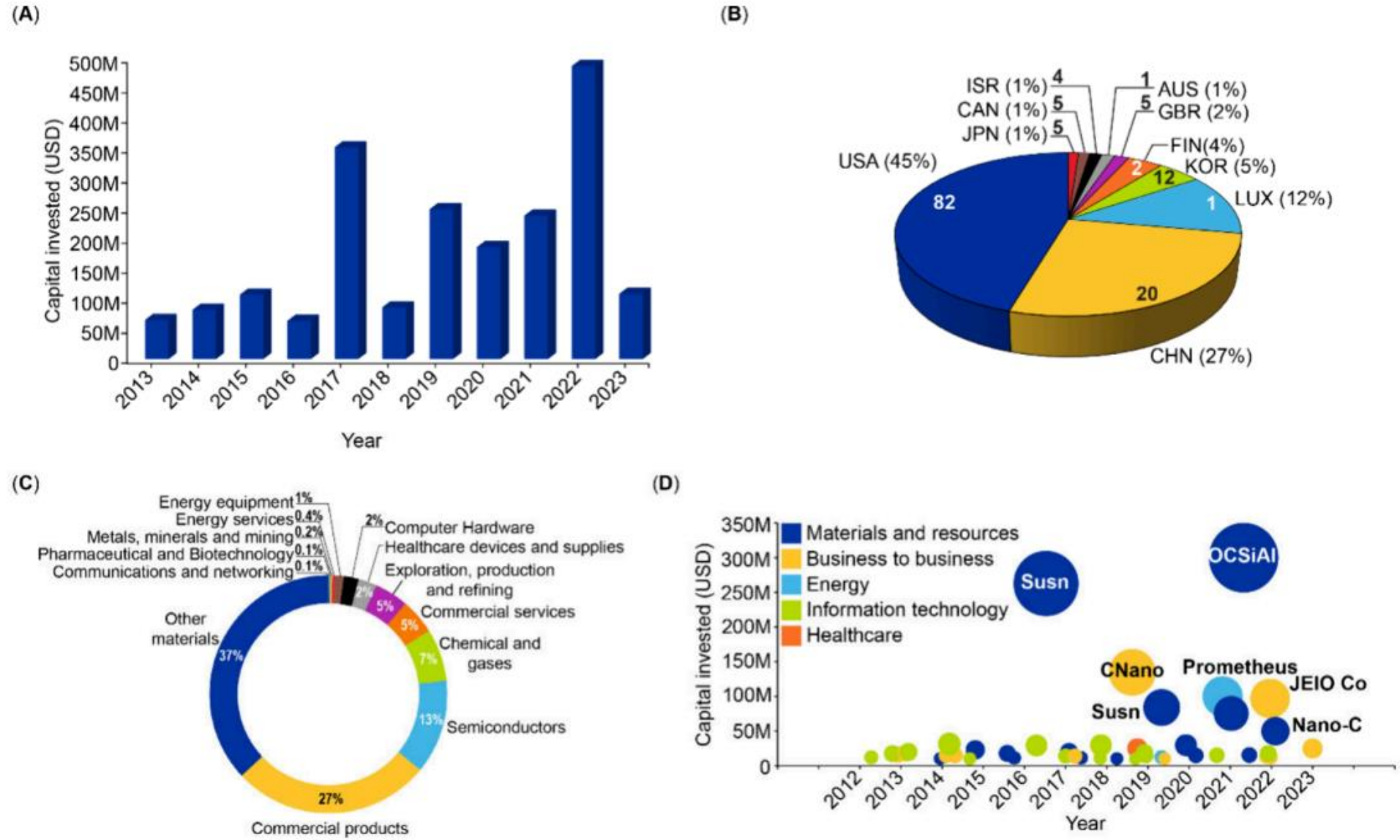


Figure 10. Commercial interest in CNTs. (A) Capital invested in the field of CNTs over 2013−2023. (B) Geographical distribution of capital invested in the area of CNTs over 2012−2023. Whole numbers (without units) indicate number of companies based in that geographical area. (C) Breakdown of capital invested across primary industry groups in the area of CNTs over 2012−2023. (D) Top 50 deals in the area of CNTs over 2012−2023 categorized by primary industry sector.

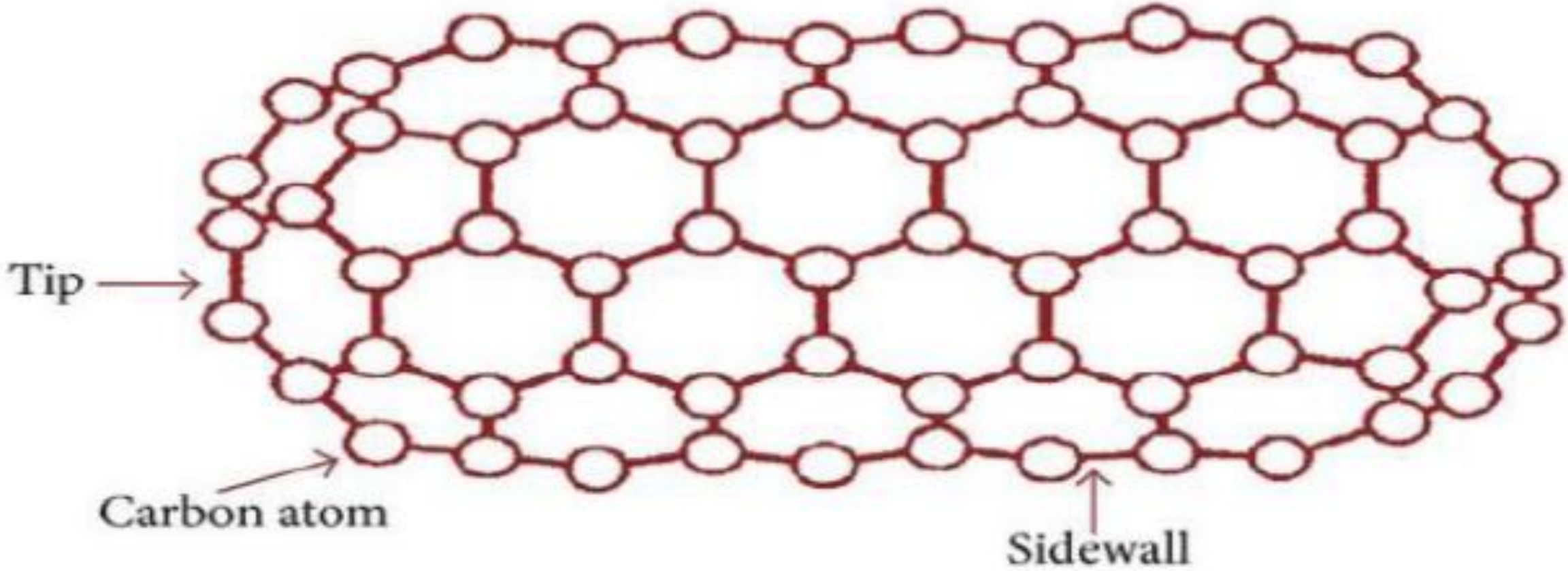


Figure 1: Structure of Carbon Nanotube.

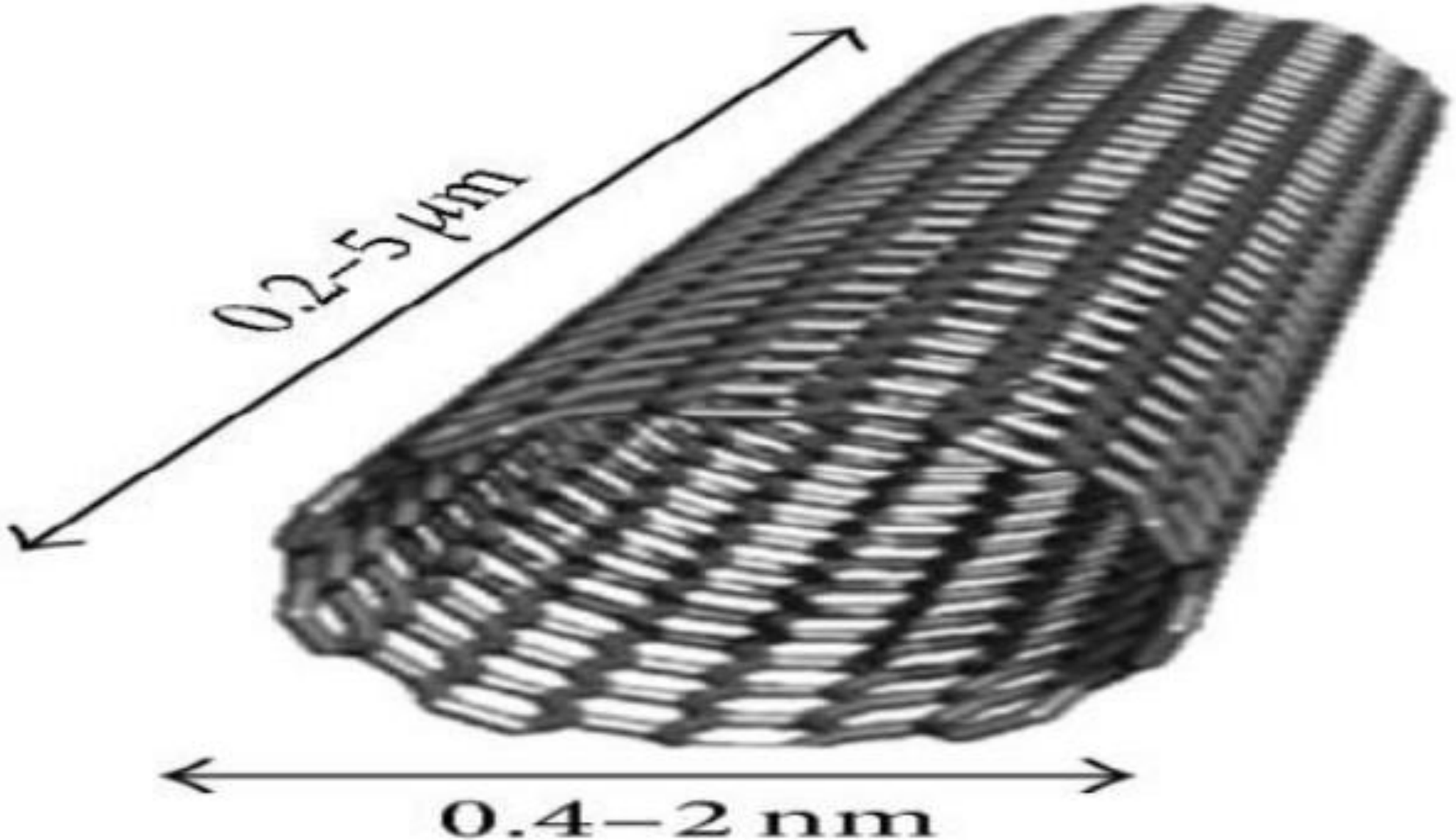


Figure 2: Single Walled Carbon Nanotube.

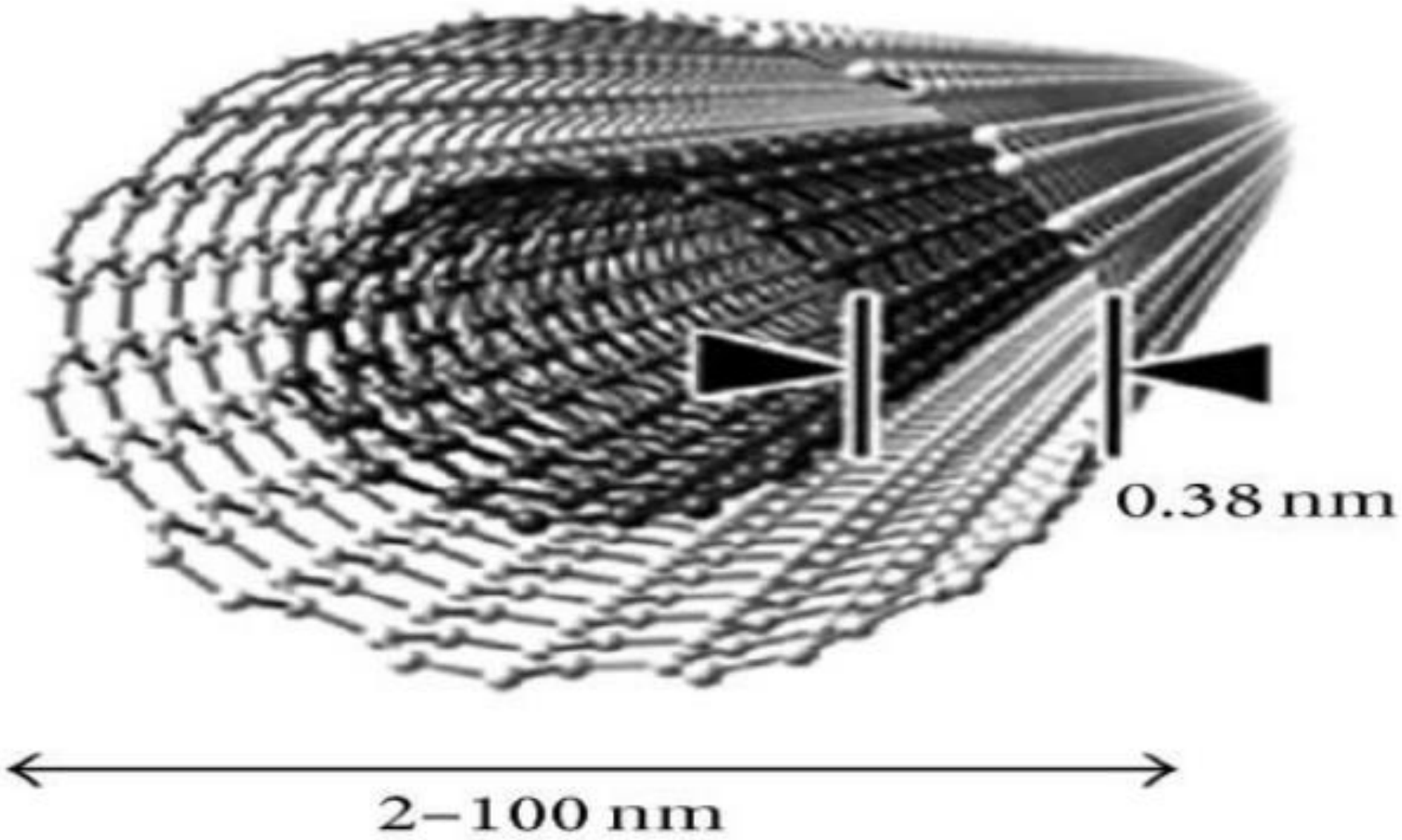


Figure 3: Multi Walled Carbon Nanotube.

Table 1: Difference between SWCNT and MWCNT [35]

SWCNT	MWCNT
It contain single layer of grapheme.	It contain multiple layer of grapheme.
It can't be produced without catalyst .	Can be produced without catalyst.
It can be easily twisted.	Can't be easily twisted.
It has simple structure.	It has complex structure.
It has less purity.	It has more purity.
It is more pliable.	Less pliable.
Bulk production is difficult.	Bulk production is easy.

Synthesis of CNTs

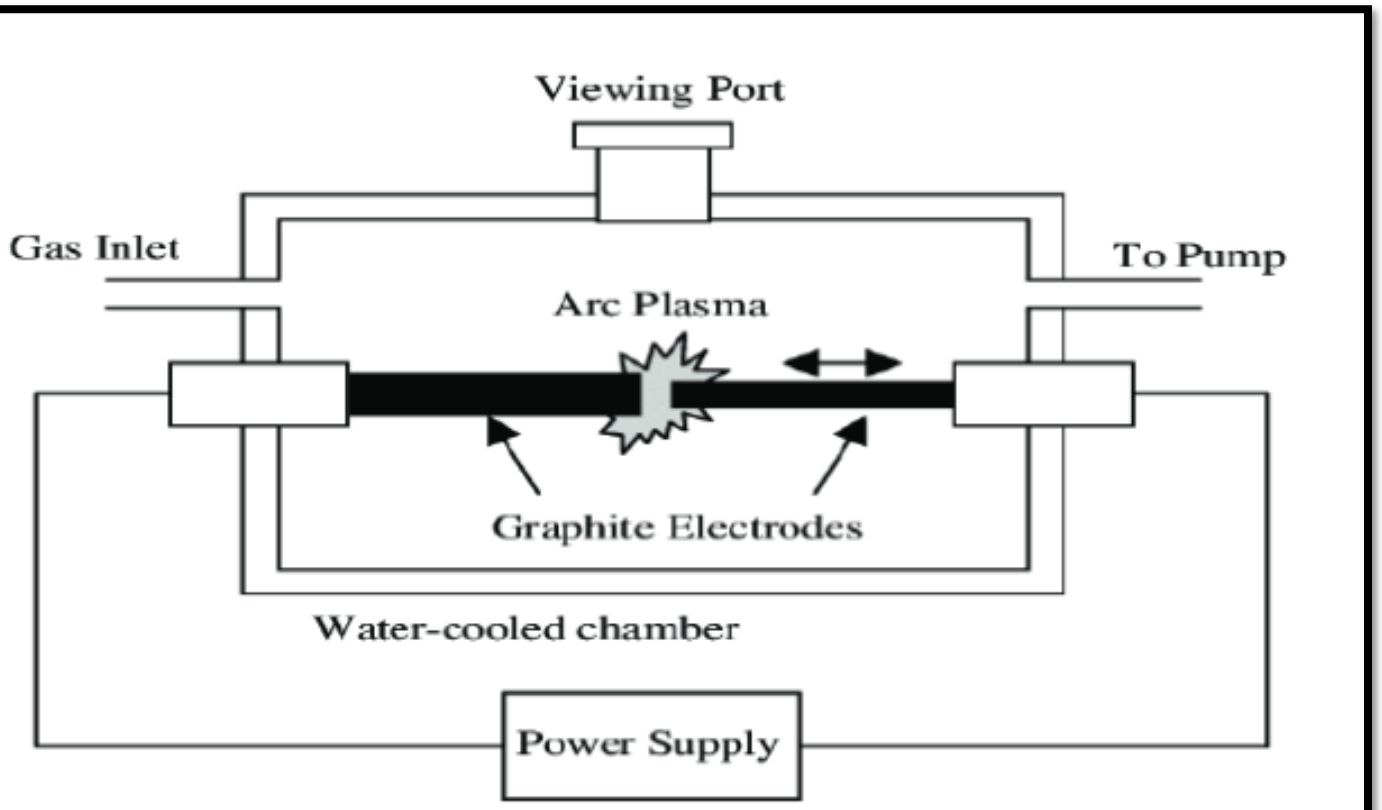


Figure 4: Arc Discharge Method.

Synthesis of CNTs

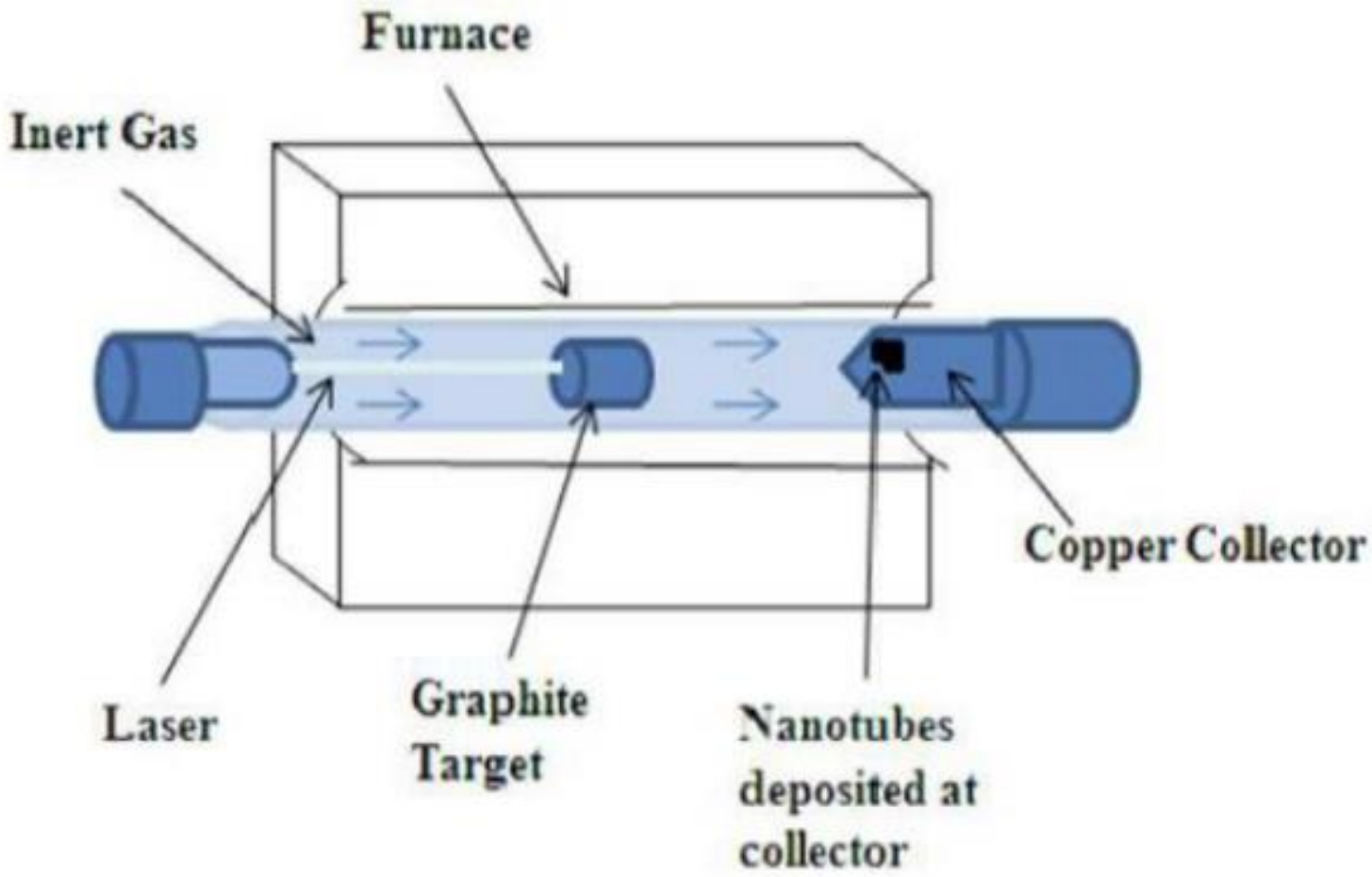


Figure 5: Laser Method.

Synthesis of CNTs

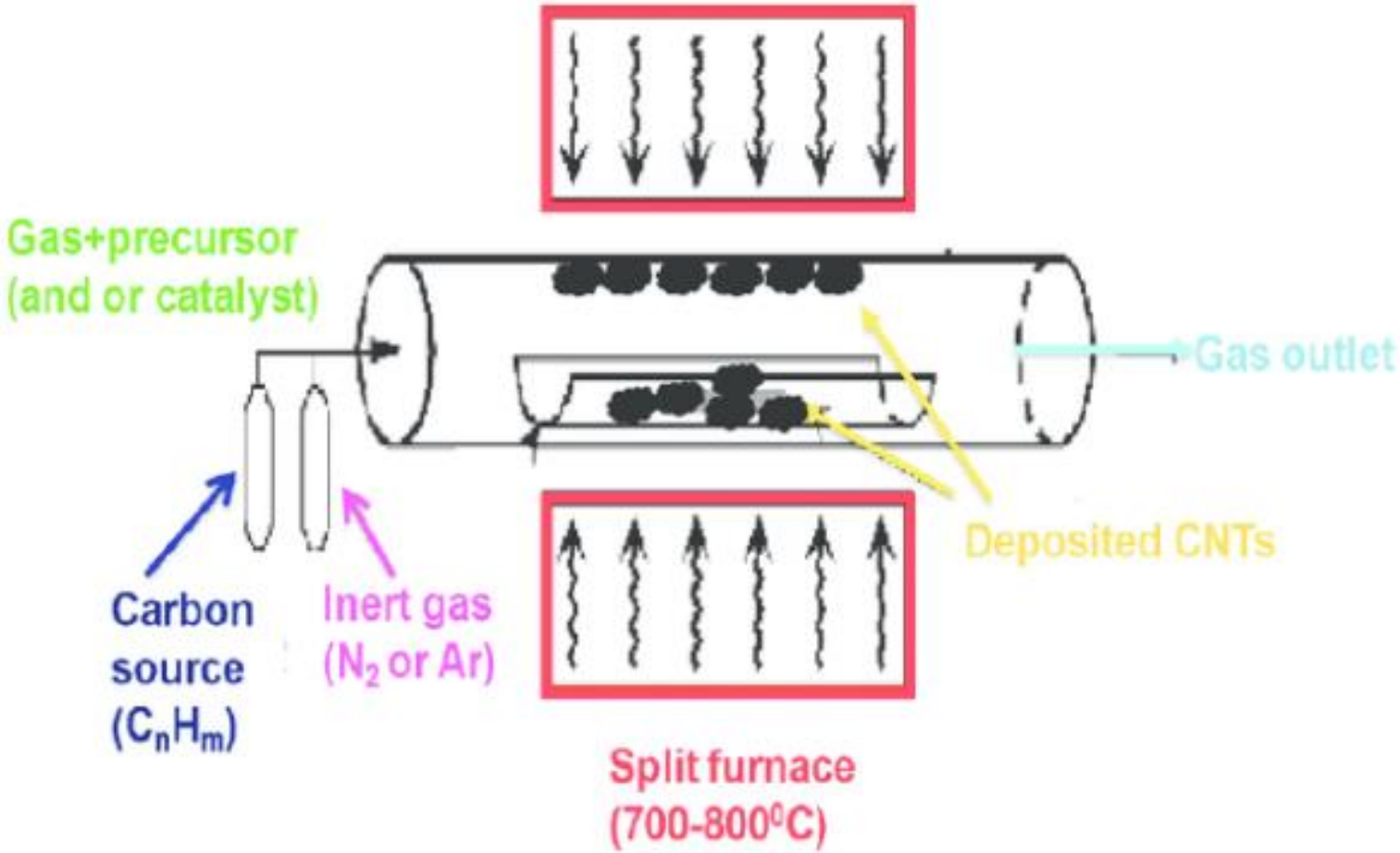


Figure 6: Chemical Vapor Deposition.

Properties of CNTs

CNTs have excellent electronic, optical, thermal, chemical, and mechanical properties.

Considering their chiral vector, carbon nanotubes containing a small diameter are either semiconducting or metallic.

The variations in conducting properties are caused by the molecular structure which results in a different band structure and thus a different band gap.

These differences in conductivity can easily be derived from the graphene sheet properties.

The specific heat of MWNTs from 10 to 300 K revealed linear dependence of the specific heat on the temperature over the entire temperature interval.

By dint of the sp2 carbon-carbon bonding CNTs show high mechanical strength.

Young's modulus value of the nanotubes have 1000 GPa, (approximately five times higher than that of steel), are considered as the best for a variety of applications.

Compared to steel CNTs can have a breaking strain or tensile strength of approximately 63 GPa, which is approximately 50 times greater than steel.

CNT Applications (Specific)

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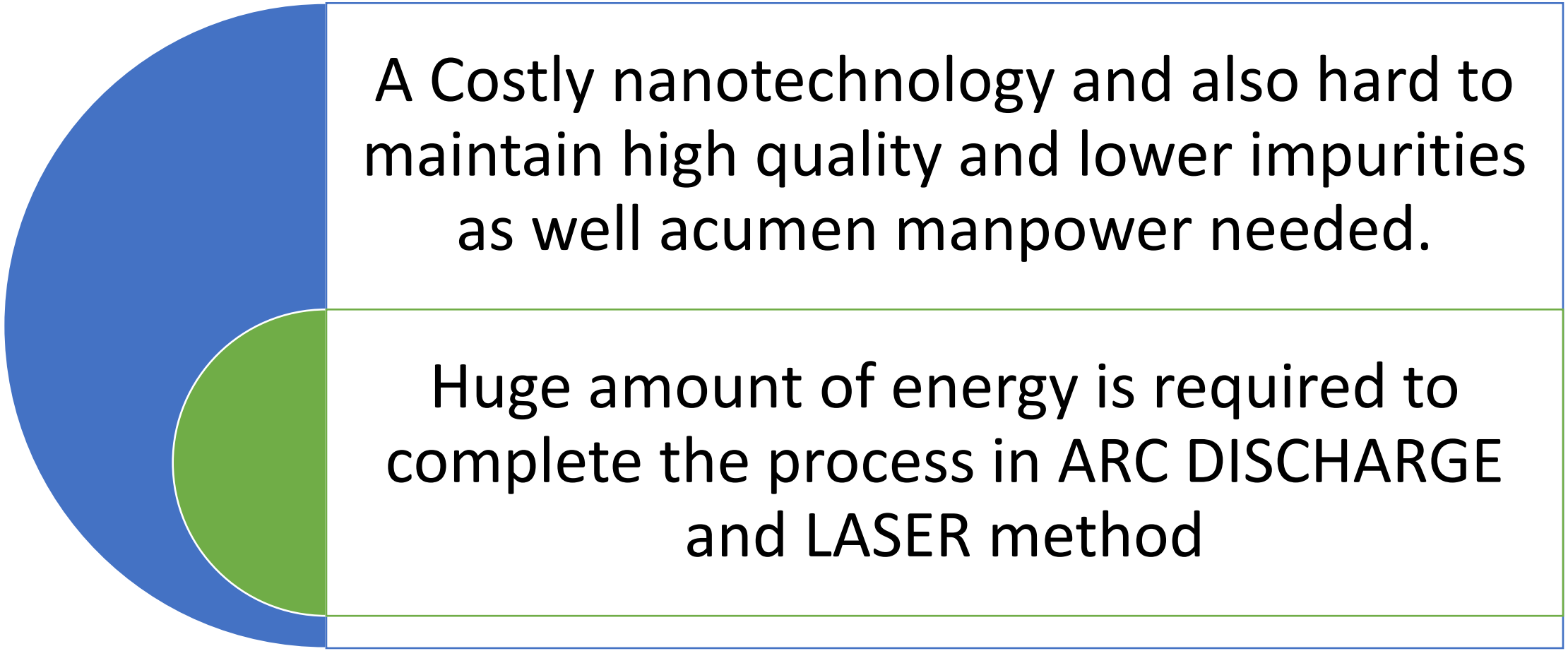
Drawbacks


A Costly nanotechnology and also hard to maintain high quality and lower impurities as well acumen manpower needed.
Huge amount of energy is required to complete the process in ARC DISCHARGE and LASER method

References

1. *Review of Carbon Nanotube Research and Development: Materials and Emerging Applications,* Kevin J. Hughes, Kavita A. Iyer, Robert E. Bird, Julian Ivanov, Saswata Banerjee, Gilles Georges, and Qiongqiong Angela Zhou*, ACS Appl. Nano Mater. 2024, 7, 18695−18713
2. *A Review on Carbon Nanotubes: Preparation, Properties and Applications,* Md Nur Karim , M.A. Sayed Patwary , S.M. Ashik Abedin , Md Riaj Hossen and Md Saifur Rahman, Journal of Research Updates in Polymer Science, 2020, 9, 96-103